Lawrence Livermore National Laboratory

"Deuterium Hugoniot up to 120 GPa (1.2 Mbar)" (U)

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Deuterium Hugoniot up to 100 GPa (1 Mbar) Pressures

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(Formerly known as Arzamas-16)

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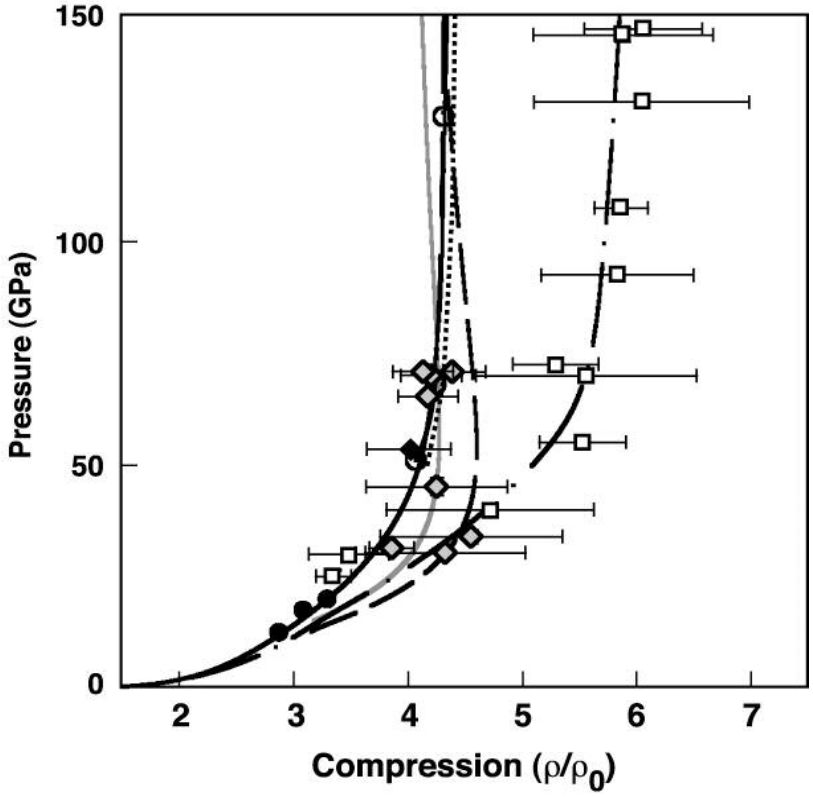
The Controversy: Which reported deuterium Hugoniot is correct?

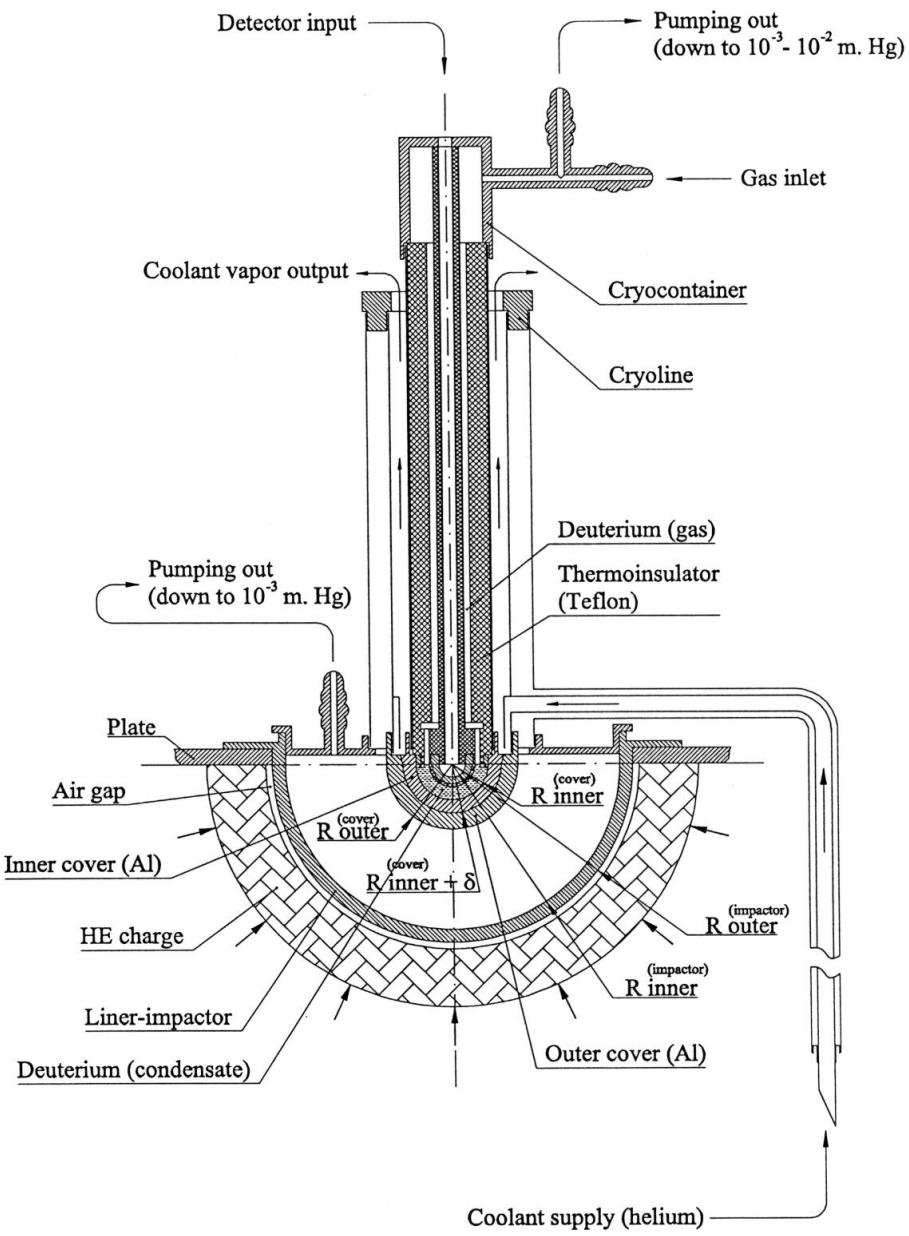


On the left is the Hugoniot measured by Knudson et al at Sandia Z Machine and numerous theories: (Sesame (Kerley), Tight-binding MD (Lee Collins), etc.

On the right is Hugoniot measured by Da Silva et al at LLNL Nova Laser and Ross' prediction.

To resolve which is correct, independent accurate measurements are needed. Arzamas has a 50-year history of doing high-quality Hugoniot measurements.

Arzamas started measuring the deuterium Hugoniot with partial support from LLNL to resolve this issue.
VNIIEF (Arzamas-16) experiments

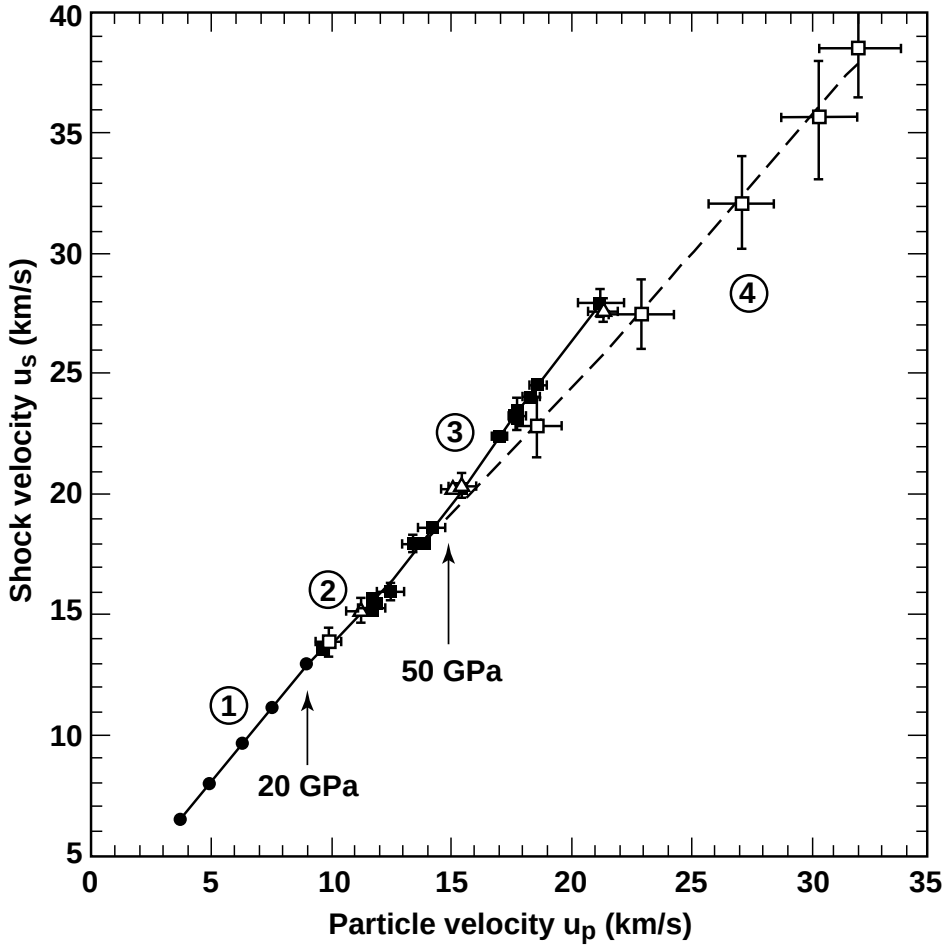


Steel shell has maximum velocity of ~15 km/s.

Corrections are made for hemispherical convergence.

~5 shots are done at each pressure to get good statistics.

Experimental data for shock velocity u_S versus particle velocity u_p for liquid deuterium



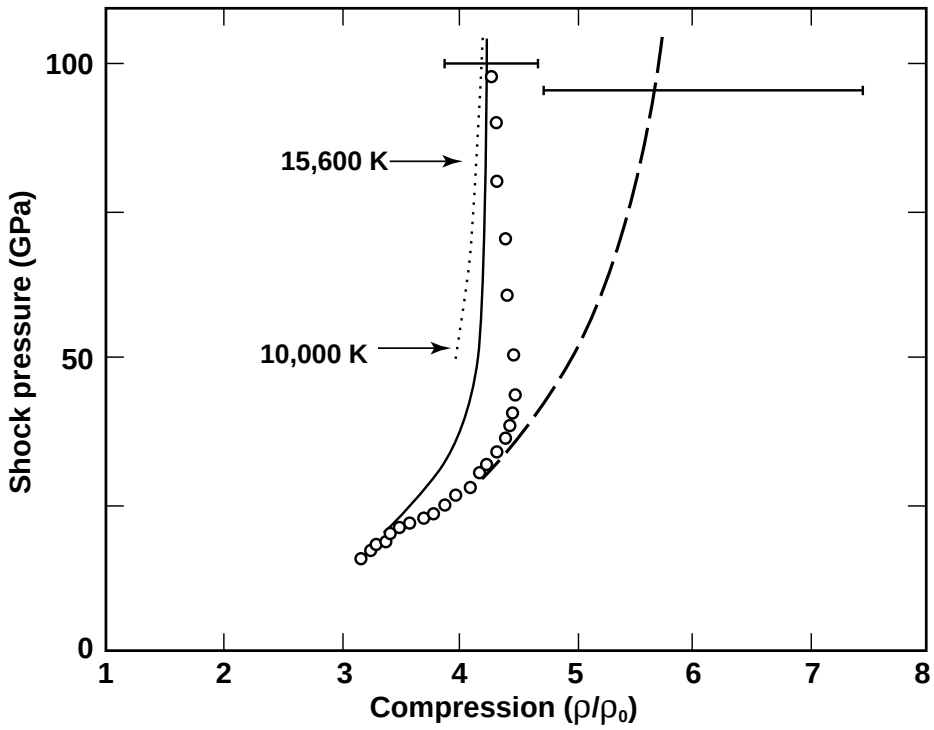
Solid circles: Nellis and Mitchell (LLNL two-stage gun)

Solid squares: Knudson et al (Sandia Z Machine)

Open triangles: Trunin et al (Arzamas HE-driven converging shocks)

Open squares: Da Silva et al (LLNL Nova Laser)

<u>Hugoniots of liquid deuterium</u>



Solid curve: calculated from fit to $u_s - u_p$ data of Sandia and Arzamas

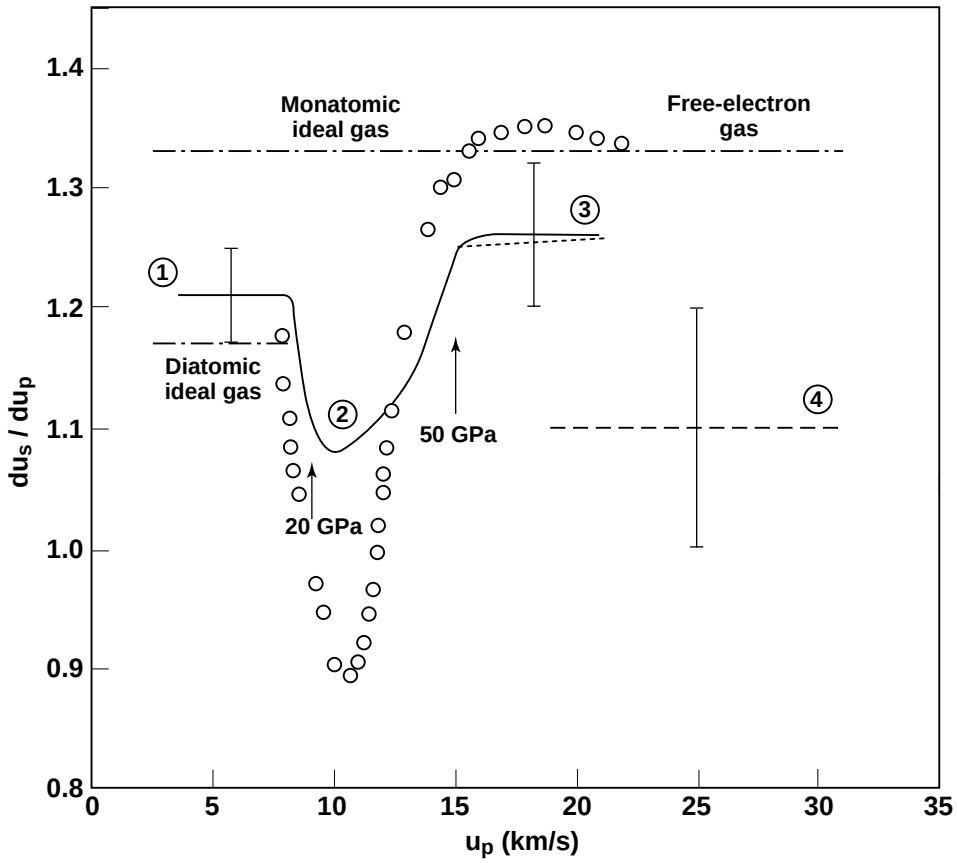
Dashed curve: calculated from fit to Nova $u_s - u_p$ data

Error bars at 100 GPa: uncertainties in fits due to uncertainties in measured u_s

Dotted curve: PIMC calculation of Militzer and Ceperley, including indicated temperatures

Open circles: *ab initio* calculations of Desjarlais (Sandia)

Slopes of $u_s(u_p)$ versus u_p for liquid deuterium



Solid curve: calculated from fit to $u_s - u_p$ data of Sandia and Arzamas

Dotted line: calculated from PIMC results

Open circles: calculated from *ab initio* results

Dot-dash: values for monatomic and diatomic ideal gases and free electrons, as indicated

Dashed line: calculated from fit to Nova $u_s - u_p$ data

Conclusions

1. Deuterium Hugoniot data measured by Sandia and Sarov are in excellent agreement from 30 to

100 GPa (0.3 to 1 Mbar). The error bars on these data are ~1/3 those of the LLNL Nova Laser.

2. This controversy is resolved by the meaning of term “error bar”. The “true” Hugoniot lies within the Nova error bars. The Sandia/ Sarov data tells us the “true” Hugoniot lies at the “stiff” end of Nova error bars.

3. Signature of molecular dissociation between 20 and 50 GPa is a relatively shallow (~10%) minimum in the slope $S = du_s/du_p$.

4. Slope $S = du_s/du_p$ cannot resolve whether or not there are any interactions between particles at Mbar shock pressures (~1 ev); i.e., S does not resolve the difference between PIMC with interactions and free electrons without interactions.

5. Kinetic energy dominates potential energy.

<u>Bottom line</u>

The Hugoniot of Sandia/Sarov is correct.